Prepared For:

Elias J. Logothetis, PE | Structural Engineer
NAVFAC Atlantic
6506 Hampton Blvd.
Norfolk, VA 23508
(757) 322-4230 Office
(757) 322-4416 Fax
elias.logothetis@navy.mil

Prepared By:

Andrew Johnson | Project Manager
Corrpro | Engineering
10260 Matern Place
Santa Fe Springs, CA 90670
(562) 944-1636 Office
(562) 946-5634 Fax
(562) 237-8845 Mobile
ajohnson@corrpro.com

FINAL REPORT

FOR

N62470-14-D-3006

VALIDATE CORROSION INHIBITOR

AT

U.S. MILITARY INSTALLATIONS

OKINAWA, JAPAN

(Corrpro Project No. – 340531156)

0	6/8/16	Issued for Approval	A. Johnson	G. Graham
REV	**DATE MM/DD/YY**	**REMARKS**	**PREPARED BY**	**CHECKED BY**

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1.0 INTRODUCTION

Corrpro, a company specialized in corrosion protection, has been contracted by the National Institute of Building Sciences to conduct testing as part of an evaluation to determine the effectiveness of corrosion inhibitor technology for steel rebar in reinforced concrete. This testing is a follow up to the testing performed after installation in January 2007 as documented in the CERL report dated August 2009, and subsequent testing performed as documented in the Corrpro 2010 report. The original project scope included two different technologies, however only the corrosion inhibitor technology was evaluated for this contract.

The corrosion inhibitor system was applied at two United States military installations in Okinawa Japan:

1. Naha Military Port – Building 306
2. Kadena Air Force Base – Kuwae Tank Farm

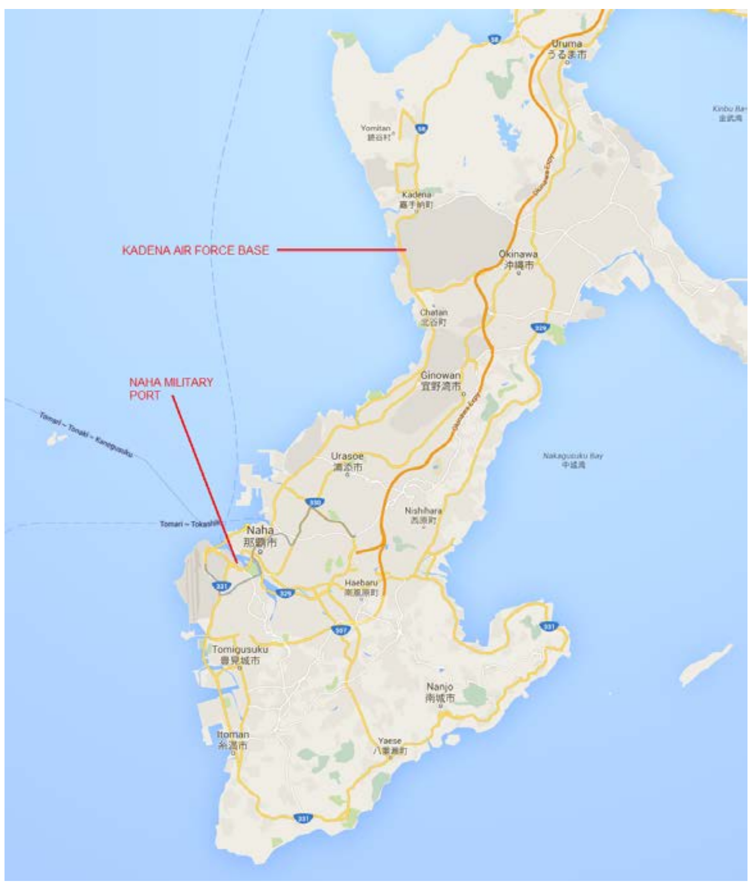

Figure 1 – Area View of Test Locations, Okinawa, Japan

Because corrosion of steel reinforcement is an ongoing expensive maintenance issue effective treatments are studied to reduce the impact of corrosion on military infrastructure. The structures selected for this test are in particularly corrosive coastal environments. The Surtreat surface applied corrosion inhibitor system which was applied to the structures under test and evaluated consists of three main components:

1) An ionic-anodic type inorganic migratory corrosion inhibitor (TPS II)

2) An organic vapor phase migratory corrosion inhibitor (TPS XII)

3) A reactive silicone surface protection agent (Repel WB)

Corrosion inhibitors are used to protect infrastructure in environments where typically other corrosion protection methods may be infeasible, impractical due to costs or implementation challenges, or where temporary corrosion protection is desired.

Concrete is generally considered as an excellent material for providing corrosion protection of steel due to its alkalinity. However, in costal environments, concrete is often saturated with water and chlorides which decrease its ability to provide effective corrosion protection. Surface sealers of silicone or siloxane formulation are often used, in addition to barrier coatings, to effectively seal the porous surface of the concrete and reduce the level of moisture and contaminates permeating into the concrete.

The evaluated Surtreat system uses a combination of migratory corrosion inhibitors to effectively reduce or stop active corrosion, with a silicone sealer to seal the concrete. This also has an added benefit of extending the useful life of the corrosion inhibitor which would otherwise be greatly reduced if the concrete remained cyclically saturated.

2.0 REFERENCES

1. ACI, American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331
   a. ACI 222R, Protection of Metals in Concrete Against Corrosion
2. ASTM International, American Society for Testing & Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428
   a. ASTM, C876, Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete
   b. ASTM, C805, Standard Test Method for Rebound Number of Hardened Concrete
3. Rilem Commission 25, PEM, Test Method II.4
4. ERDC/CERL TR-09-27 Report "Corrosion Prevention of Rebar in Concrete in Critical Facilities Located in Coastal Environments at Okinawa", by Construction Engineering Research Laboratory (CERL), Dated August 2009
5. Final Report, Corrpro, Dated September 2010

3.0 SAFETY

All work on site shall be performed in accordance with Corrpro standard health & safety policy as well as site specific requirements. A daily job safety analysis (JSA) will be completed and the following personal protective equipment (PPE) will be utilized: hard hat, safety glasses, steel toe shoes, gloves, ear plugs, and high visibility vests. No hazardous materials or wastes will be used or generated.

4.0 EQUIPMENT

Corrpro is an ISO 9001 company and maintains all field equipment calibrated, traceable, and in good working order. Equipmented used for testing on site included:

- Calibrated Fluke Digital Multi-Meters
- Silver/Silver Chloride Reference Electrode
- Copper/Copper Sulfate Reference Electrode
- Wire Leads
- Rainbow pH Indicator Solution
- Galvapulse GP-5000
- Rebar Locator
- Drill & Masonry Core Bit
- Schmidt Rebound Hammer
- Rilem Tubes
- Digital Psychrometer
- Chipping Hammer & Misc. Tools

5.0 FIELD TESTING

Two project sites in Okinawa were selected due to the harsh environment and visible deterioration of concrete. Two culvert bridges located at Kuwae Tank Farm (referred to in the CERL project report ERDC/CERL TR-09-27 as bridges 2 and 3) were chosen for application of the Surtreat system. Bridge 2 received the entire 3-part Surtreat system. Bridge 3 only received the inorganic inhibitor and silicone sealant. The second project site was inside a warehouse at Naha Military Port. Two sections of ring girder were selected, one treated with the Surtreat system, and the other coated with the NASA coating which was not part of this evaluation but was found to be greatly deteriorated.

Corrpro tested Bridge 2 at the Kuwae Tank Farm, Kadena AFB (figure 2), and Section 1 of the ring girder at Building 306 in the Naha Military Port (figure 3). Corrpro performed the evaluation of the corrosion inhibitor system during the weeks of March 14th and 21st, 2016 in the same manner as was previous done by Corrpro in 2010.

<u>Kuwae Tank Farm</u>

Bridge 2 that received the full Surtreat system was evaluated for effectiveness of the system. The same three specific areas chosen for the 2007 inspection were previously tested in 2010 as shown in Figure 2 were evaluated. These areas were designated as areas A, B, and C. All three areas were on vertical surfaces. No cracking or spalling of the treated area was visually apparent. A few small square patches were observed that were not originally present at the time of treatment, and the circumstances of their installation are unknown. Figures 3, and 4 show the condition of Bridge 2 as found in 2016.

Figure 2 – View from upstream of Bridge 2 at the Kuwae Tank Farm, Kadena AFB, 2010

Figure 3 – View from upstream of Bridge 2 at the Kuwae Tank Farm, Kadena AFB, 2016

Figure 4 – View from downstream of Bridge 2 at the Kuwae Tank Farm, Kadena AFB, 2016

Table 1 compares the most recent corrosion rate values with the previously measured values before treatment, 6 months after treatment, and approximately 3 years after treatment. The data from sites A, B, and C are combined as resulting data was similar in nature. Galvapulse measurements, as shown in Figure 5, showed that corrosion rate remains significantly reduced from pre-treatment levels. Although the corrosion rates have increased since 2010 they are still below the first posttreatment evaluation in July 2007. Measurements ranged from 2.1 µm/yr to 22.4 µm/yr and were more consistent around lower sections of test areas which had lower resistance likely from the reduced effectiveness of the silicone treatment over time.

Table 1 – Corrosion Rate Measurements on Bridge 2, Kuwae Tank Farm

	Before Treatment	After Treatment			Overall Reduction
	January 2007	July 2007	July 2010	March 2016	
Median (50% Probability)	29.8 µm/yr (1.17 mpy)	7.8 µm/yr (0.31 mpy)	6.9 µm/yr (0.27 mpy)	7.7 µm/yr (0.30 mpy)	74%
Average	37.4 µm/yr (1.47 mpy)	13.1 µm/yr (0.52 mpy)	7.1 µm/yr (0.28 mpy)	11.5 µm/yr (0.46 mpy)	79%

Figure 5 – Measuring corrosion rate

Water absorption was negligible and the silicone sealer is still effectively sealing the concrete from moisture. Rilem tube tests, as shown in Figure 6, performed in the same location as earlier testing showed virtually no measurable water absorption. Wetting out concrete on the test areas required a series of repeated wettings over a period of several hours to lower concrete resistance sufficiently for measurements to be made. Figure 7 shows an area of concrete where sealer was still inhibiting the absorption of water after several applications of water. Areas of application of the Surtreat system was still readily evident by a white coloration, or lack of discoloration, on the concrete where it was applied.

Figure 6 – Collecting rilem test tube, white area where Surtreat system applied

Figure 7 – Sealer still evident after several wettings of the concrete

A series of compressive strength measurements were made using a Schmidt hammer on an area of concrete previously tested between sections A and B. The average measured value was 5200 psi, which is an increase from the previous measurements in 2010 and 2007. Concrete pH and depth of carbonation were measured using a rainbow indicator solution. The pH measured immediately under the treated surface was in the range of 9-10 at a depth of 1/8”.

Naha Military Port

The Surtreat system was previously applied at the warehouse building no. 306 in Naha Military Port. Section 1 where the system was applied is a section of ring girder adjacent to the exit door in section A of the building. Visually, the ring girder identified as Section 1 with the Surtreat system had no apparent changes since the last testing performed in 2010 as shown in Figures 8 and 9. Section 1 appeared in good shape without signs of deterioration. However, the other ring girder identified as Section 2 with the NASA coating had a clear visual indication of the coating delaminating from the concrete surface. This deterioration can be seen in Figure 10 below.

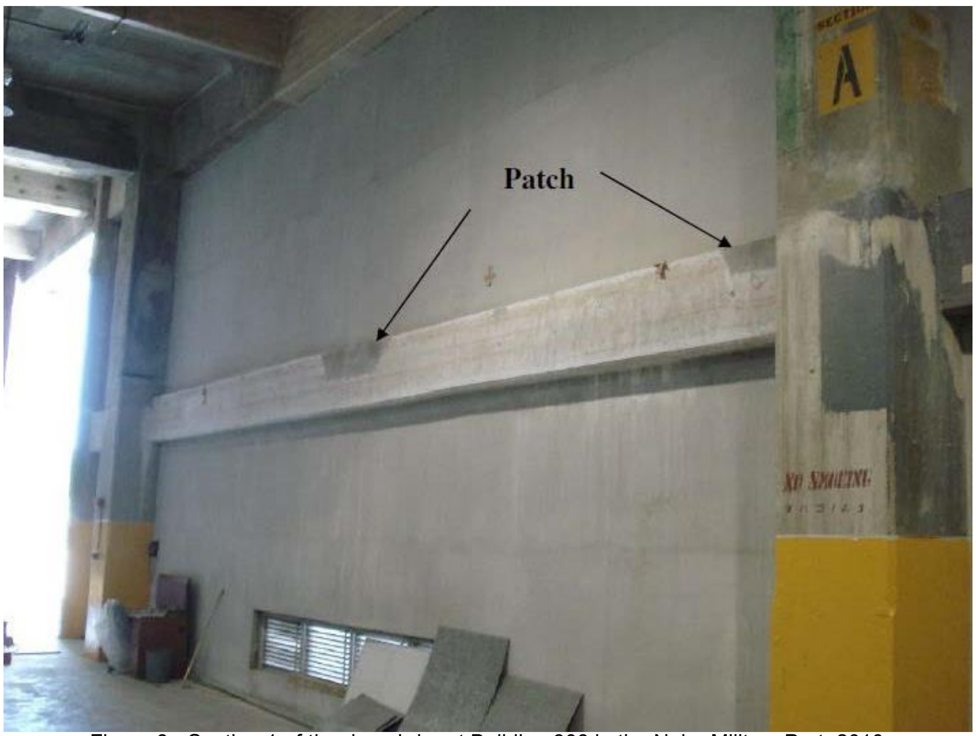

Figure 8 - Section 1 of the ring girder at Building 306 in the Naha Military Port, 2010

Figure 9 - Section 1 of the ring girder at Building 306 in the Naha Military Port, 2016

Figure 10 - Section 2 of the ring girder at Building 306 in the Naha Military Port, 2016

Table 2 below provides a comparison of the most recently obtained data to that previously collected. It should be noted that the concrete was difficult to wet because of the sealer and required numerous applications of clean water. Rebar in Section 1 showed low corrosion rate compared with prior to treatment, and was even a bit lower than the 6 month after treatment evaluation. There was wide variation in the data, though, and this is believed to occur from the high resistance in the concrete being effectively sealed from the silicone sealer. To ensure continuity Corrpro cored concrete to rebar to make a physical connection onto the horizontal reinforcement. Corrpro also removed the silicone sealer at some locations to take readings without the influence of a sealer. Average measurements with sealer removed provide a corrosion rate of 8.46 μm/yr with corrosion rate reduction of 80%.

Table 2 – Corrosion Rate Measurements on Section 1 Building 360, Naha Military Port

	Before Treatment	After Treatment			Overall Reduction
	January 2007	July 2007	July 2010	March 2016	
Median (50% Probability)	41.4 μm/yr (1.63 mpy)	5.7 μm/yr (0.22 mpy)	4.9 μm/yr (0.19 mpy)	6.2 μm/yr (0.24 mpy)	85%
Average	61.3 μm/yr (2.41 mpy)	24.3 μm/yr (0.96 mpy)	14.0 μm/yr (0.55 mpy)	25.7 μm/yr (1.01 mpy)	68%

Rilem tube water penetration, as seen in Figure 11, yielded no noticeable absorption after several hours. Schmidt Hammer compressive strength of Section 1 averaged 5700psi which were close to the values previously obtained in 2010. As seen in Figure 12, pH testing provided a pH of approximately 9 to a depth of 1.5 inches where the pH subsequently increased.

Figure 11 – Rilem test tubes placed on section 1 ring girder.


Figure 12 – Core removed over horizontal rebar, and pH indicator applied

Figure 13 – Visual comparison of section 1 ring girder in to ring girder adjacent to exit door.

6.0 ANALYSIS

The 3-part Surtreat system, based upon measurements of corrosion rate and moisture penetration, is effectively protecting the rebar from corrosion. To date, an average reduction in the corrosion rate by 79 to 80% has been realized. Visually the sealer is still well intact indoors and outdoors which is made apparent by the white to opaque coloration present and inability for moisture to readily penetrate the treated areas.