# CHARACTERIZATION OF COATING PERFORMANCE IN VARIOUS NATURAL EXPOSURE ENVIRONMENTS

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**Abstract:** The subject paper presents updated inspection data from a Federal Highway Administration study of the effect of local environments on the degradation of alternative bridge coating materials. Exposure data covers up to nine years of service in several diverse environments, including sites representative of marine, industrial, and rural service environments. Paint deterioration is characterized as the result of local atmospheric parameters, time of wetness, and airborne contaminants

## INTRODUCTION

Corrosion control of structural steel remains a critical issue for bridge engineers. For low-alloy carbon steels the most common corrosion control method is the application of protective coatings. The coatings may be applied over abrasive-blasted steel or as maintenance overcoats.

Typical coating or material selection is based on a variety of performance reports. In many cases, these performance reports may not be indicative of the severity of the local environment. It is common to find coating recommendations for a marine environment based on historical performance in a rural environment, which is generally less corrosive. Rapid coating failure may occur in the harsher environment. Similarly, accelerated corrosion may be expected of weathering steels in salt-laden marine environments. Yet such materials may perform as designed a short distance from a major chloride-source.

Recognizing these issues, the Federal Highway Administration initiated a program to (1) develop methods for characterizing the local atmosphere, (2) identify sites around the U.S. with differing levels of environmental contaminants, and (3) conduct exposure testing of coated materials. Deterioration of these materials was to be related to the local environment.

## EXPERIMENTAL PROCEDURES

The program included a literature review to identify the key parameters in the atmospheric deterioration of ASTM A 588 weathering steels and organic coatings. This included a review of papers published at NACE and SSPC conferences and affiliated journals. It also encompassed a broad computer-based search of major technical literature. In total over 100 papers were identified and reviewed.

We also identified several sources of basic environmental data. For the subject program, the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) database seemed the most useful (1). The NADP/NTN is a 200-station wet deposition-monitoring network. Sites are located nationwide. The program characterizes regional patterns of deposition on a national scale by excluding monitoring site locations in close proximity to point sources or large urban centers. The data are able to suggest the local trends with respect to deposition of $SO_x$, $NO_x$, $Cl^-$, and rainfall. The subject program sought to evaluate the ranges of these principal atmospheric constituents with respect to material degradation.

The potential combinations of such atmospheric constituents are limitless. Based on the program budget, seven sites were selected for testing. In four cases, we exposed test samples at the same monitoring site used by the NADP/NTN program. This allows for a more exacting correlation of local pollutants and observed deterioration. In the remaining cases, data was obtained from a nearby NADP site, from NOAA data, or by supplemental monitoring equipment (2).

The sites are listed below:

Oregon Site (OR) – This site is known as OR-10 (NADP/NTN), outside of Eugene, Oregon. The station is in the H. J. Andrews Experimental Forest in Lane County, Oregon. The exact location is latitude 44° 12' 44", longitude 122° 15' 21", and elevation 450 meters. The site is intended to be representative of a high-time-of-wetness area with relatively few atmospheric pollutants.

Louisiana Site (LA) – This site is known as LA-12 (NADP/NTN), near Lafayette, Louisiana. The station is the Iberia Research Station in Iberia County, Louisiana. The exact location is latitude 29° 55' 47", longitude 91° 42' 55", and elevation 6 meters. The site is intended to be representative of a high-time-of-wetness warm area with average levels of atmospheric pollutants.

Massachusetts Site (MA) – This site is known as MA-01 (NADP/NTN), located near the northern-most point of Cape Cod, on the ocean side. The station is the North Atlantic Coastal Lab in Barnstable County, Massachusetts. The exact location is latitude 41° 58' 33", longitude 70° 01' 29", and elevation 41 meters. This was a colder marine site with mid to high-level chloride exposure, average rainfall, and relatively low levels of atmospheric pollutants.

Indiana Site (IN) – This site is known as IN-34 (NADP/NTN), located in the northwest corner of Indiana, southeast of Chicago and near Michigan City. The station is the Indiana Dunes National Lakeshore in Porter County, Indiana. The exact location is latitude 41° 37' 57", longitude 87° 05' 16", and elevation 208 meters. This site was representative of high $SO_x$, high $NO_x$, low chlorides, and average rainfall.

New Jersey Site (NJ) – This site is not an NADP/NTN location. The site is in Sea Isle City, New Jersey. It is located within 100 feet of the mean high tide of the Atlantic Ocean. It is a severe marine site with high saltfall.

Florida Site (FL) – This site is not an

NADP/NTN site. It is located in the Miami, Florida area several miles inland from the ocean. The site location is latitude 25° 56' 00", longitude 80° 25' 00" and elevation of 2 meters.

Arizona Site (AZ) – This site is located just north of Phoenix in New River, AZ. It is not an NADP/NTN site. The site location is latitude 33° 54' 00", longitude 112° 08' 00", and elevation 610 meters.

At each location, test specimens were exposed. Coated steel panels were exposed at each location. Weathering steel samples were exposed at each location except for the FL and AZ test sites.

The coating systems were applied to four ASTM A 36 steel samples abrasive-blasted to an SSPC SP-10 surface preparation. They were also applied to two, pre-weathered (SSPC Surface Condition "D") panels cleaned to an SSPC SP-3 surface condition. We applied all coatings by the manufacturer's directions. On two of the SP-10 panels, eight intentional scribes (1/4-inch diameter) were made on the front face. This allowed for statistical sampling of under-film corrosion. The other two panels incorporated a U-channel on the front face and were exposed without a scribe. The two SP-3 panels were exposed with two holidays along the lower face of the panel. All panels were exposed for weathering facing south at a 45$^{o}$ angle to horizontal. Eight coating systems were investigated:

| Sample ID | Generic Coating Description |
|---|---|
| **1** | Inorganic zinc/epoxy/urethane |
| **2** | 3-coat water-based acrylic |
| **3** | Waterborne inorganic zinc/polysiloxane |
| **4** | 3-coat silicone alkyd |
| **5** | Calcium sulphonate alkyd |
| **6** | Organic zinc/epoxy/urethane |
| **7** | Epoxy/urethane |
| **8** | 3-coat moisture cured urethane |

Data collection for the coating systems has consisted of visual inspections only. ASTM D 610 and D 714 rating systems have ranked panels. Cut-back has been examined visually.

## RESULTS AND DISCUSSION

The present discussion is an update to the summary of the voluminous data available. Due to staggered starts of the different exposure sites, not all coupons have been exposed for the same time frame. The current report concerns exposures of:

| Site | Previous Exposure Duration-Days | Current Exposure Duration-Days |
|---|---|---|
| **AZ** | 730 | N/A |
| **FL** | 730 | N/A |
| **IN** | 1274 | 3080 |
| **LA** | 952 | 3204 |
| **MA** | 328 | 2616 |
| **NJ** | 699 | 3020 |
| **OR** | 933 | 3086 |

The Florida (FL) and Arizona (AZ) sites are no longer active and will not be included in the current discussion. To date the inspections at all other locations have been based on visual data for the coating systems.

Chemistry

The range of chemistry at each location was nominally:

| | Data from NADP/NTN Monitors (except NJ) | | | | | | Data from Site Monitors | |
|---|---|---|---|---|---|---|---|---|
| **Location** | Cl, ppm | $SO_4$, ppm | $NO_3$, ppm | Conduc-tivity, µS/cm | pH | PPT, cm | Avg. Temp °F | % Time Wet |
| **Arizona** | 0.28 | 0.90 | 1.04 | 11.3 | 5.1 | 24 | 71.6 | 4% |
| **Florida** | 1.39 | 1.17 | 0.74 | 20.1 | 5.0 | 125 | 75.2 | 48% |
| **Indiana** | 0.22 | 2.50 | 2.03 | 21.9 | 4.7 | 90 | 51.0 | 27% |
| **Louisiana** | 0.74 | 1.08 | 0.83 | 13.3 | 4.8 | 140 | 71.2 | |
| **Massachusetts** | 2.41 | 1.64 | 1.31 | 27.0 | 4.5 | 122 | 50.5 | 55% |
| **New Jersey** | 27 | 25 | N/A | | 4.2 | 94 | 48.4 | 51% |
| **Oregon** | 0.25 | 0.26 | 0.27 | 4.7 | 5.2 | 223 | 47.4 | 70% |

The data for the Indiana, Louisiana, Massachusetts, and Oregon sites correspond to the site of the test samples and the 1994/1995 exposure period. There is no NADP/NTN site at the Florida, Arizona, or New Jersey test site. For the Florida test site, 1996/1997 data from Cape Canaveral is displayed. For the Arizona site, 1996/1997 data from three sites in Arizona were averaged to be representative of the actual Phoenix-area test site. For the New Jersey site, our personnel obtained local pollutant 1996 data using slightly different methodologies than NADP/NTN. Most significant of these was the use of open collection apparatus during rain periods.

The site monitor data is obtained from the actual exposure sites. The time-of-wetness data is for panels boldly exposed in a horizontal position (5° angle for FL and AZ sites). Temperature is for a sheltered sensor.

Of the seven test sites, the New Jersey site had the highest chloride levels. This is not unexpected given the location was adjacent to the Atlantic Ocean. The Massachusetts site also has a higher than average chloride exposure. This is also reflected in the enhanced conductivity. The Oregon site was the “cleanest” and had the highest rainfall and the highest time-of-wetness. The Indiana site appeared to have the highest $SO_x$ and $NO_x$ exposure.

Paint Performance

Figures 1 and 2 show the average paint panel rusting data as a function of site location and surface preparation over time. The data are averages for all coating systems. There was reduced general rusting over the SP-10 surface preparation versus the SP-3 surface preparation. The harshest site following 8 years of exposure is the New Jersey test site, where extensive deterioration was noted on the alkyd systems.

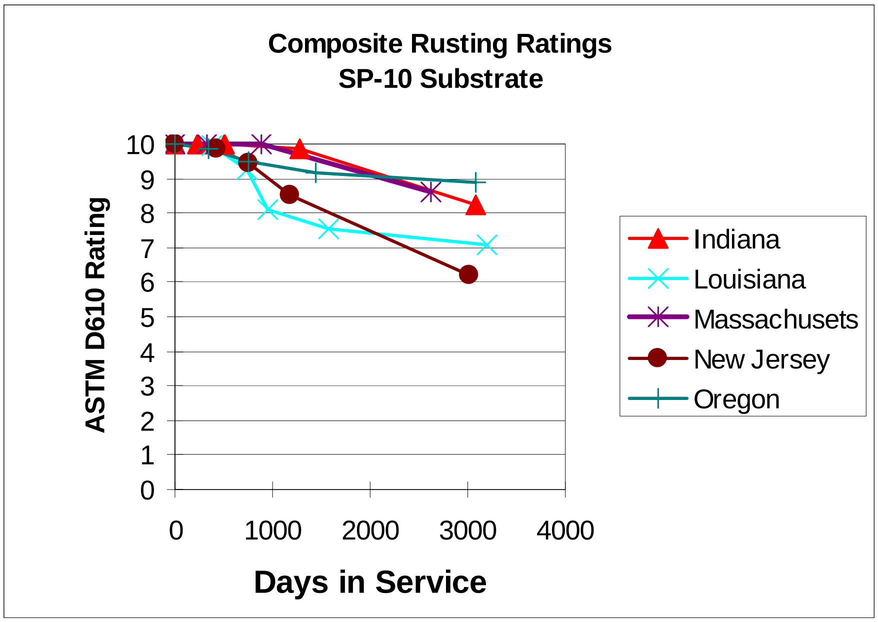


**Figure 1. Average ASTM D 610 Rating for SP-10 Substrates.**

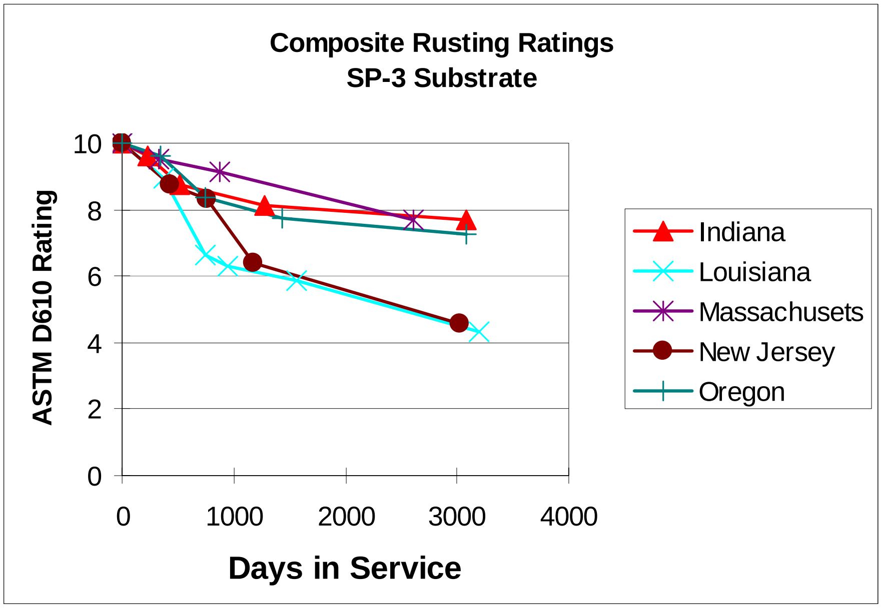


**Figure 2. Average ASTM D 610 Rating for SP-3 Substrates.**

Over the SP-3 surface preparation, the harshest sites after 8 years of exposure are the Louisiana and New Jersey test sites. The poorly performing Louisiana systems were the inorganic zinc-based systems, the 3-coat alkyd, the calcium sulphonate system and the moisture cured urethane. The poorly performing New Jersey systems were the IOZ polysiloxane system, the 3-coat alkyd system, the calcium sulphonate system, and the moisture-cured urethane system.

With respect to blistering tendencies, there was little significance to any (minimal) blistering over the SP-10 surface preparation (all rated above 9). Figure 3 shows the blistering data over the SP-3 surface preparation. Note the numerical ranking is a composite of the blister size and blister density with 10 representing no blistering. These data suggest that the worst blistering over the hand-tool cleaned surface is observed at the Oregon, New Jersey, and Louisiana test sites. This is based on the overall trend in blistering of these locations, which can improve with time. Blistering of paint can improve as blisters break (rupture) or if their size is reduced during periods of low time of wetness (where less water is available for osmotic blistering).

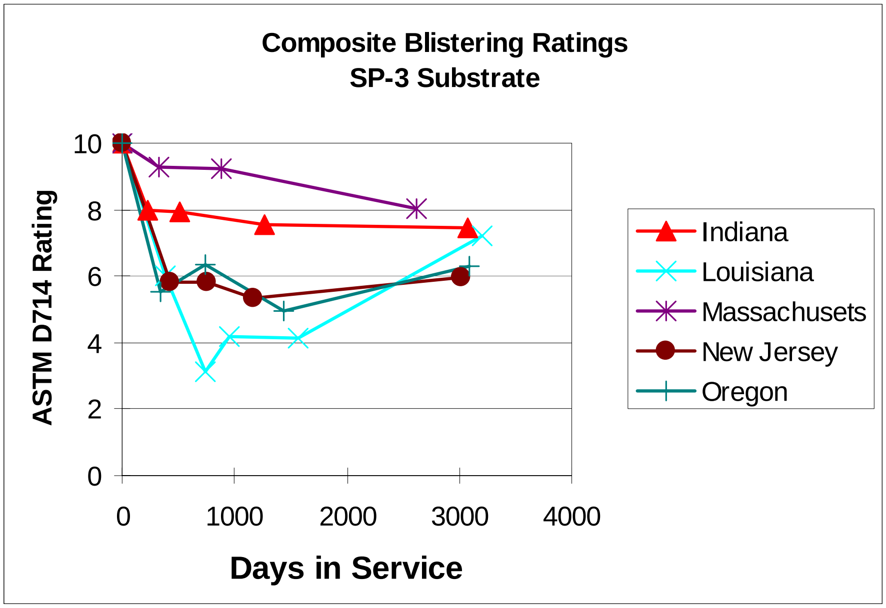


**Figure 3. Average Composite ASTM D 714 Blister Rating SP-3 Substrates.**

At the Oregon site, the worst performing systems were the 3-coat acrylic, the 3-coat silicone alkyd, the calcium sulphonate system, the organic zinc epoxy urethane system, the epoxy urethane system, and the moisture cured urethane system. In New Jersey, the worst performing materials were the 3-coat silicone alkyd system, the calcium sulphonate system, the epoxy-urethane system and the moisture cured urethane system. In Louisiana, almost all systems exhibited significant blistering. The only system to show no blistering was the water-borne inorganic zinc system with a siloxane topcoat. In this case blistering may have been masked by the higher modulus of the topcoat.

Figures 4 and 5 show the cutback results for the SP-10 and SP-3 surface preparation conditions, respectively. For SP-10 conditions the most aggressive site was New Jersey, with all others having similar performance. The poor performers were the 3-coat waterborne acrylic system, the 3-coat silicone alkyd system, the calcium sulphonate system, the epoxy urethane systems and the moisture cured urethane system.

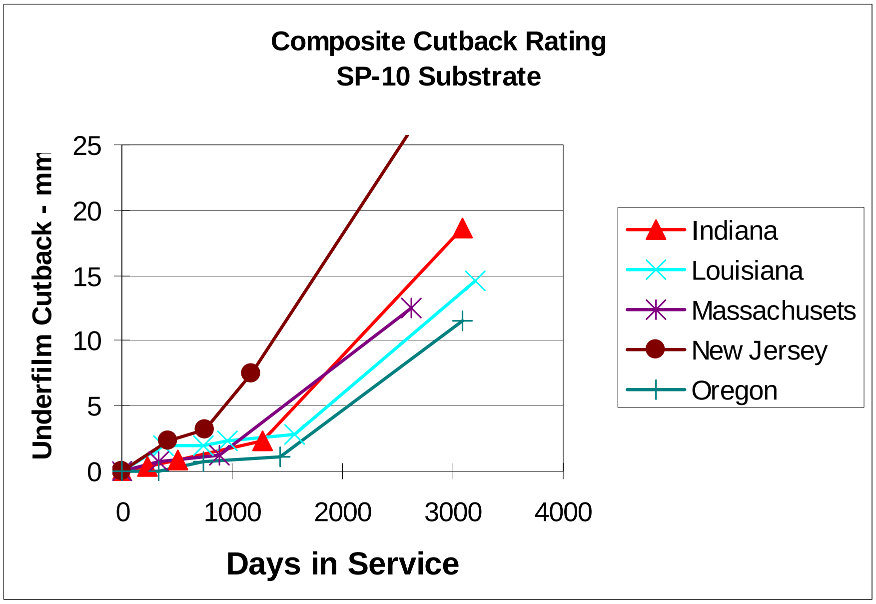


**Figure 4. Average Cutback for SP-10 Substrates in millimeters.**

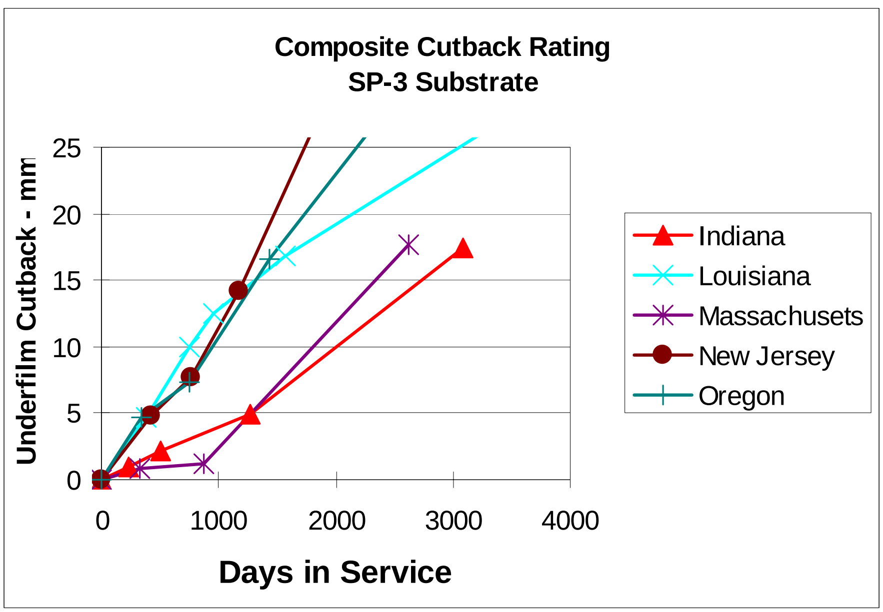


**Figure 5. Average Cutback for SP-3 Substrate in millimeters.**

For SP-3 the most aggressive sites were Louisiana, New Jersey and Oregon. In Oregon the systems with the most cutback were the silicone alkyd system, the calcium sulphonate system, inorganic-zinc system, the epoxy/urethane system, and the moisture cured urethane system. All systems exposed at the New Jersey site were poor performers. In Louisiana the poor performers were the inorganic-zinc based system, the calcium sulphonate system, and the epoxy/urethane system.

Summary of the Performance by Location

The following tables summarize the paint performance at each site with respect to several critical parameters (after 2 and 8 years, respectively). The critical parameters used to determine whether coatings had deteriorated at a site are a rating of less than 8 for rusting and blistering in accordance with ASTM D610 and ASTM D 714 respectively and cutback from holidays of more than 0.075 inches. The data in the tables show the percentage of the total exposure population which met the critical parameters described above. (The higher percentages indicate more samples with deterioration.) In general the New Jersey site now appears the harshest overall, very closely followed by the Louisiana site.

| **Observation – 2 years** | AZ | FL | IN | LA | MA | NJ | OR |
|---|---|---|---|---|---|---|---|
| **Rusting SP-10 (<8)** | 0% | 25% | 0% | 13% | 0% | 13% | 13% |
| **Rusting SP-3 (<8)** | 0% | 38% | 25% | 50% | 13% | 38% | 25% |
| **Blistering SP-10 (<8)** | 0% | 13% | 0% | 0% | 0% | 0% | 13% |
| **Blistering SP-3 (<8)** | 13% | 25% | 63% | 88% | 25% | 88% | 63% |
| **Cutback SP-10 (>0.075)** | N/A | N/A | 50% | 38% | 0% | 50% | 0% |
| **Cutback SP-3 (>0.075)** | N/A | N/A | 50% | 88% | 0% | 75% | 38% |

| **Observation – 8 years** | AZ | FL | IN | LA | MA | NJ | OR |
|---|---|---|---|---|---|---|---|
| **Rusting SP-10 (<8)** | N/A | N/A | 13% | 25% | 13% | 33% | 19% |
| **Rusting SP-3 (<8)** | N/A | N/A | 25% | 67% | 38% | 63% | 31% |
| **Blistering SP-10 (<8)** | N/A | N/A | 25% | 17% | 0% | 20% | 50% |
| **Blistering SP-3 (<8)** | N/A | N/A | 50% | 33% | 38% | 56% | 75% |
| **Cutback SP-10 (>0.075)** | N/A | N/A | 100% | 100% | 100% | 100% | 100% |
| **Cutback SP-3 (>0.075)** | N/A | N/A | 100% | 100% | 100% | 100% | 100% |
| ***Cutback SP-10 (>0.25)*** | *N/A* | *N/A* | *63%* | *63%* | *69%* | *88%* | *38%* |
| ***Cutback SP-3 (>0.25)*** | *N/A* | *N/A* | *50%* | *80%* | *69%* | *100%* | *69%* |

The original criterion of 0.075 inches of cutback resulted in observations for all samples at all sites. While this does show a progression of deterioration, it does not permit for the comparison on performance between locations. Relaxing the criterion to 0.25 inches allowed variations in performance for substrates and between sites to be observed. Interesting to note is that despite relaxing the criteria, for most sites the number of observations still increased and the relative rank order of sites is still similar.

Performance by Coating System

The following table summarizes the performance data for each coating system at all sites by the same performance criteria. The data show the percentage of the total exposure population meeting the observation criteria. Overall the best performing systems were those with an inorganic zinc primer. The worse performing systems were the alkyd, calcium sulphonate and moisture-cured urethane systems.

| **Observation – 2 years** | IOZ/ EP/ UR | Acrylic | IOZ/ Siloxane | Alkyd | Ca. Sul-phonate | OZ/ EP/ UR | EP/UR | MCU |
|---|---|---|---|---|---|---|---|---|
| **Rusting SP-10 (<8)** | 0% | 14% | 0% | 57% | 0% | 0% | 0% | 0% |
| **Rusting SP-3 (<8)** | 14% | 0% | 14% | 43% | 71% | 0% | 0% | 71% |
| **Blistering SP-10 (<8)** | 0% | 0% | 14% | 14% | 0% | 0% | 0% | 0% |
| **Blistering SP-3 (<8)** | 14% | 71% | 43% | 71% | 57% | 43% | 43% | 71% |
| **Cutback SP-10 (>0.075)** | 20% | 20% | 0% | 60% | 40% | 0% | 40% | 40% |
| **Cutback SP-10 (>0.075)** | 40% | 60% | 0% | 60% | 60% | 40% | 80% | 60% |

| **Observation – 8 years** | IOZ/ EP/ UR | Acrylic | IOZ/ Siloxane | Alkyd | Ca. Sul-phonate | OZ/ EP/ UR | EP/UR | MCU |
|---|---|---|---|---|---|---|---|---|
| **Rusting SP-10 (<8)** | 0% | 0% | 22% | 40% | 89% | 0% | 10% | 0% |
| **Rusting SP-3 (<8)** | 33% | 10% | 20% | 70% | 100% | 30% | 30% | 80% |
| **Blistering SP-10 (<8)** | 25% | 22% | 0% | 20% | 56% | 40% | 20% | 0% |
| **Blistering SP-3 (<8)** | 33% | 90% | 10% | 40% | 80% | 50% | 50% | 70% |
| **Cutback SP-10 (>0.075)** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| **Cutback SP-10 (>0.075)** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| ***Cutback SP-10 (>0.25)*** | *20%* | *70%* | *40%* | *50%* | *90%* | *70%* | *90%* | *80%* |
| ***Cutback SP-3 (>0.25)*** | *44%* | *90%* | *20%* | *60%* | *100%* | *90%* | *100%* | *80%* |

These tables also show that after 7 to 9 years of exposure, cutback for all holidays is above the original observation point for all samples. As above, the criterion for this observation was relaxed and variations in performance were observed. This still supports the conclusion that an inorganic zinc primer does improve performance. All other systems have similar cutback performance.

<u>Specific Paint Performance by Location</u>

Figures 6 and 7 show the panels exposed at the harshest (New Jersey) and most benign (Massachusetts) sites. These pictures readily show the differences in coating performance at the each end of the spectrum. Even casual observation of these photos would lend itself to the conclusion that the New Jersey site is more aggressive than Massachusetts.

Considering the systems as applied over a SP-10 or SP-3 substrate, there is more variation in performance of the New Jersey samples as compared to the Massachusetts exposures. The predominant deterioration mode to classify these samples is rusting in New Jersey compared to cutback in Massachusetts. The variation in the New Jersey samples more readily identify the better performing systems, whereas the limited differentiation in the Massachusetts samples only identify poor performers at this point.

**New Jersey Exposure Site – 3020 days (8.3 years)**
**SP-10 Substrate**

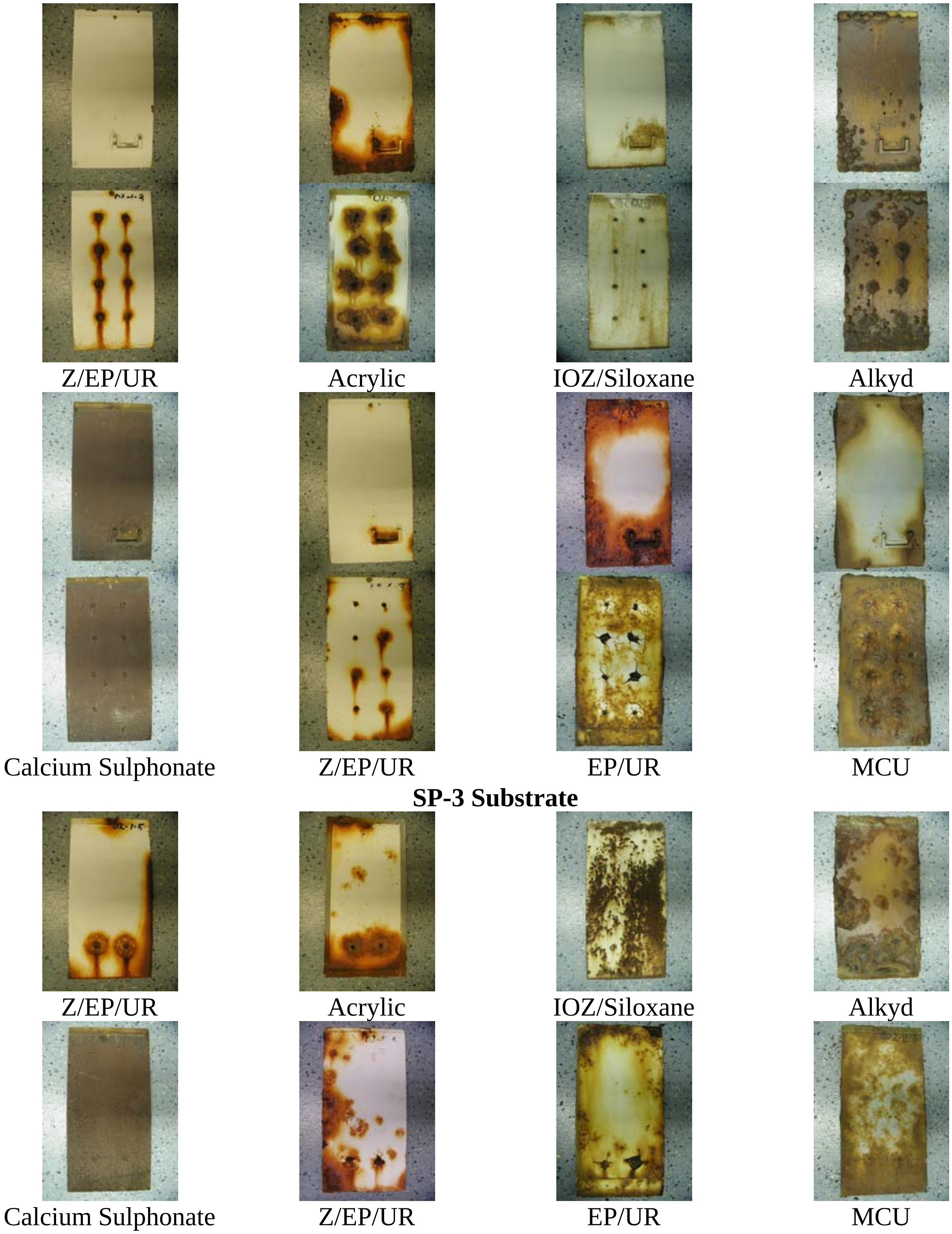


**Figure 6. Representative Photographs of Panels - NJ Site.**

**Massachusetts Exposure Site – 2616 days (7.2 years)**
**SP-10 Substrate**


**Figure 7. Representative Photographs of Panels - MA Site.**

## CONCLUSIONS

1. The samples exposed at most test sites have begun to show significant difference in performance such that an optimum system (or systems) could be selected for use.

   - Optimum system for a specific location can be selected by considering performance and cost of materials. Since each environment is unique, this should be done on a case-by-case basis.

2. The primary influence for coating performance, regardless of the environment, continues to be the cleanliness of the surface. With a clean, SP-10 surface, the better coating systems show little deterioration in any of the environments as compared to their SP-3 prepared counterparts. In more benign environments (Massachusetts), most of the coating systems are still performing well.

3. Over an SP-3 surface preparation, there is no single correlation between environmental factors and paint deterioration. The presence of high chloride levels (New Jersey) seems to contribute greatly to the rate of coating deterioration. However, a high chlorides concentration alone does not explain the reason for the harsh environment in New Jersey. Other factors such as temperature and time-of-wetness also contribute to the severity of the environment. The relationship between these factors and the coating deterioration cannot be determined at this time. Discounting chlorides, in general, through-film rusting appears to correlate mostly with increased average temperature. Blistering and cut-back appear to correlate best with a high time-of-wetness. Increased conductivity also appears to increase cut-back in sufficiently wet environments.

4. After this period of exposure coating performance at the various sites over a SP-3 substrate lends itself to the selection of three or fewer candidate systems as a maintenance coating. Over a SP-10 substrate only the New Jersey site samples have performance that can be used to demonstrate which coating(s) would be optimum in this environment.

5. To distinguish between systems in the remaining sites over a SP-10 substrate further evaluations at a later period are required.

Test samples remain exposed at these locations for follow-on inspections at future intervals.

## REFERENCES

(1) Refer to http://nadp.sws.uiuc.edu for more information

(2) NOAA data from http://www.ncdc.noaa.gov for more information